TECH NOTE: Noise analysis with QuantumX and catman®AP from HBM

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Abstract

This TECH NOTE basically deals with the acquisition and analysis of acoustic signals by means of a **measuring microphone**, **QuantumX** measurement electronics, an MX410B amplifier, and **catman®AP** software. If catman Easy is used, the **EasyMath** Add-on module is mandatory. The aim of this description is to show the possibilities and potential of a general analysis of all the crucial quantities - mechanical, thermal, electrical, acoustic, visual and positional.

Introduction

HBM enjoys a global reputation for state-of-the-art test & measurement products and provides flexible, metrological, data acquisition and analysis solutions for the physical quantities used in development, experimentation, production and service. In the mechanical world, HBM stands for the "universal measuring chain" – from transducers for torque, rotational speed, force, pressure, strain and displacement, to amplifier systems, to powerful software – all from a single source.

The acoustic performance of machines or system components is becoming ever more important in development and experimentation, production sampling, and in service use. After all, the "extra quantity" of acoustics is often crucial for comfort, occupational health and safety, and brand image in the complete product life cycle. Additional measuring tools are often used when acoustics are involved. As a result, users have to battle with different devices, user interfaces, philosophies and data formats.

The QuantumX and catman®AP metrological solution from HBM not only acquires mechanical, thermal, electrical and digital bus signals such as CAN, as well as GPS or video, but now also acoustic signals. All the Information can be quickly and easily visualized, offset, analyzed and saved in a file. The saved data can also be relevantly prepared, saved again and included in a test report, or made accessible to a customer or supplier, with the same software.

The additional functions of sound level analysis in dB(A), with psychoacoustic evaluation according to loudness, and frequency analysis in the 2D spectrogram, make QuantumX and catman®AP the perfect metrological toolbox:

Check, test and analyze with one tool!

There are many advantages to using a single tool for parallel, synchronized acquisition of all the interesting measurands:

- Rapid analyses in just a few clicks
- Saving in a file and exporting to different formats
- Speedy comparison with earlier measurement results (trend analyses)
- A compact and portable solution for service use
- The speedy analyses of connection changes or cracks, for example, allows faults to be quickly cleared

TECH NOTE puts this forward as a starter kit:

- QuantumX measurement module with dynamic inputs for connecting microphones
  - MX410B with sample rates up to 100 kS/sec and a 40 kHz bandwidth per channel
- catman®AP 4 with new functions
  - Converting sound pressure to sound level in dB(A) in the time domain
  - FFT frequency analysis, 2D spectrogram, frequency triggers
  - Report generation, data export

Typical applications

Typical applications in development, experimentation, production and service:

- Development of motors, gearboxes, clutches, bearings, linkage joints or mechatronic components in general
  - Test: Function, run-up measurement, performance, durability, lifetime
- Individual testing in production (inspection)
  - Sampling: Function with acoustic constraints (e.g. car interiors), so that each product is manufactured to the same high quality.
- Stationary structure monitoring (condition monitoring)
  - Monitoring: The condition of trains and the effect on infrastructure and environment (weight and distribution on the wheels, (wheel ovality, acoustic emissions / ambient noise, etc.)
- Service tasks on existing machines
  - Diagnosis: Routine inspection, calibration/adjustment, continuous monitoring, troubleshooting

Typical requirements

The following are known requirements in connection with acoustics:

- Presentation over time, frequency, angle or other quantities such as displacement, rotational speed (tachometer)
- Presentation in a color spectrogram as power-spectral-density (PSD)
- Overall level characteristic in dB(A)
- Band-limited level characteristic in dB(A)

Categorizing acoustics

Acoustics is the science of sound. In an industrial environment, we mostly look at unwanted noise. The typical audible frequency range is between 20 and 20000 Hz. In German-speaking countries in particular, the terms *noise, vibration, and harshness*, or **NVH** for short, are widespread in the automotive market, and describe audible noise, or perceptible vibrations in vehicles or machines. *Harshness* is the subjective transition region between 20 and 100 Hz that is both audible and perceptible. The reason for *vibration* is the force introduced by a vibration source into vibration-transmitting structures, such as self-induced stick-slip effects, that are either the side-effects of desirable friction, or the unwanted result of friction between solids, that leads to the emission of **structure-borne noise** and ultimately, audible **air-borne noise**. Typical examples of NVH are stick-slipping windscreen wipers, transmission whine, a gripping clutch, or noisy vehicle air conditioning.

An elastic solid can take up shear stress, as well as normal stress. So in a solid that is unrestricted on all sides, two different kinds of structure-borne sound waves propagate, so-called longitudinal waves and transverse waves. These waves propagate independently of one another. In both cases, the sound velocity, as with air-borne noise, is not dependent on the frequency. The sound velocity is affected by density, the *modulus of rigidity* (transverse waves) and the *modulus of elasticity* (longitudinal waves).

The recording and analysis of structure-borne noise plays a major role in engineering. It is possible to analyze the acoustic properties of systems and/or the technical status of a machine, e.g. bearing wear. The development of cracks and material failure can also be recorded. The evaluation of the electrical signals obtained covers finding characteristic frequency components and sound amplitudes.

With NVH, it is a matter of avoiding vibrations that could reduce comfort.

Phänomen	SPL [dB(A)]
Flugzeug mit Strahltriebwerken, 25 m, Schmerzschwelle	140
Live-Konzert	120
Schwerer Lkw in geringem Abstand	100
Geräuschvolle Büroatmosphäre	80
Unterhaltung, 1 m	60
Zimmer in der Wohnung	40
Flüstern, Blätterrauschen	20
Hörschwelle	0

Microphones

The function of the microphone is to convert pressure vibrations and the associated sound pressure into electrical signals. Typically, the amplitudes are measured in decibels (dB). Frequency ranges are analyzed in Hertz (Hz).
The types of microphone most frequently used include:

- The pre-polarized electret condenser microphone
- The externally polarized condenser microphone
- The piezoelectric microphone (acoustic pressure sensor)
- The fiber-optic microphone
- The carbon microphone
- Micro-electromechanical systems (MEMS)

The following factors are important in the choice of microphone:

- Sensitivity, typically between 10 and 220 dB
- Frequency range, e.g. 20 … 20,000 Hz
- Dynamic range
- Robustness

Measurement, testing and calibration

Nationally and internationally, the ISO 9001 standard is the most widespread and significant standard in Quality Management (QM). It demands that the measuring devices and test equipment are calibrated with traceability to national standards – which can be done periodically or before each measurement task. A calibration can, for example, be performed on the basis of measurement standards that are subjected to regular test equipment monitoring. Mechanical, electrical and thermal measured quantities can be calibrated by HBM.

Measuring microphones should also be calibrated with traceability to national standards. IEC61094 and ANSI S1.40 are the standards to mention here. Standard IEC60942 on the other hand describes the **acoustic calibrators**. Of the three classes, the laboratory standard (LS) has the closest tolerances. Class 1 devices are intended for field applications. A class 1 sound level meter should be calibrated with a class 1 calibrator.

Standard IEC61672 defines the electro-acoustic performance standards for sound level meters. The sound level meters considered here have the following focus:

- The sound exposure level
- The time-average sound level
- The exponential time-weighted sound level

In our practical setup, a so-called "sound level calibrator" of the LARSON DAVIS CAL200 series is used for **calibration**. The calibrator is based on ANSI S1.40-2006 and IEC60942-2003 class 1. The calibrator can emit the two sound levels 94 dB and 114 dB at a frequency of 1000 Hz as a reference.

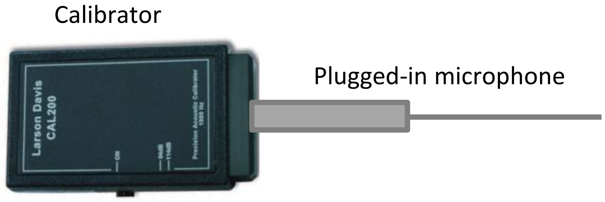


Image caption: Calibration

QuantumX data acquisition modules

The data acquisition system QuantumX supports a broad range of different sensor technologies and is therefore capable of acquiring many physical quantities at the same time. The "Swiss army knife of measurement technology" is an expression that has taken hold throughout the industry among thousands of customers to describe QuantumX – the universal measuring tool. The product is widely used, especially in the research and development of vehicles, ships and aircraft and their system parts as well as machines and drives, but also in construction technology. Numerous other applications include inspection, troubleshooting and optimization of production. QuantumX is universal, compact, portable, freely scalable, sturdy and distributable, making it an ideal DAQ system for both mobile and stationary applications.

The main measurement quantities typically include mechanical, electrical and thermal quantities such as strain, displacement, torque, rotational speed, force, voltage and current, temperature, pressure, oscillation, vibration, speed, position, acceleration, as well as flow rate and many other physical quantities of a dynamic or static system. With connected microphones and technical software support in catman AP, acoustics is another quantity to include.

The number of acquired measured quantities is virtually unlimited. The distributable system concept offers advantages here as the measurement equipment can be placed close to the measuring point, thus allowing for the use of short ready-made sensor lines. That increases measurement quality for certain types of sensors, reduces installation costs and offers significantly greater flexibility for recurring tasks.

MX410B – the universal amplifier with maximum signal bandwidth

The MX410B **universal amplifier** is the flagship of the QuantumX series.
The module has an incredibly wide range of functions. Each of the 4 channels can be individually configured, and supports:

- Resistivity in full and half bridges for SGs or piezo-resistive transducers
- Current-fed piezoelectric transducers (IEPE / ICP®)
- Normalized voltage: +/- 10 V
- Normalized current: 0 / 4 …. 20 mA
- Sample rate/filters
  - 24-bit sigma-delta AD converter
  - 100 kS/s per channel or in two-channel operation up to 200 kS/s, bandwidth to 40 kHz
  - Digital Bessel or Butterworth filters
- Can be extended with clip-on adapters:
  - 300 V CAT II: SCM-HV
  - SG quarter bridge: SCM-SG120 or -SG350
- Analog output of the universal input: +/- 10 V, optional filter, 150 µs latency
- Internal module calculations of the root mean square value (RMS) or peak value (PEAK) are possible

Virtually any system expansion is possible. Synchronization mechanisms such as PTP, FireWire, NTP, IRIG-B or EtherCAT are available for this. The channels are electrically isolated from one another for supply and communication, which allows an extremely high signal-to-noise ratio (SNR) of approx. 120 dB.

Acquisition at a high sample rate is possible for any transducer type with MX410B. The high signal bandwidth is ideal for connecting microphones.

The high-resolution digital module MX460 is a good addition for **rotational analyses** of internal-combustion engines or rotating shafts in general. The module helps on all 4 channels:

- Digital frequency signal of HBM torque transducers, e.g. with a 60 kHz mid-frequency
- Digital rotary transducers/encoders with/without index, e.g. 2 tracks A and B, 2048 pules per revolution, index pulse
- Inductive rotary transducers, pick-ups, e.g. crankshaft sensor
- Pulse-width modulated signals (PWM) for determining the pulse width as % or time
- Internal module calculations allow an analysis of torsional vibration or a peak value analysis (PEAK)

Of course, other amplifiers or modules of the series can also extend the overall system, such as for acquiring the quantities of voltage and current (MX403B), CAN-Bus (MX840B, MX471) or temperatures (MX1609KB).

The full description of the modules can be found on our website at hbm.com.

The catman®AP software

The powerful catman®AP software from HBM can roughly be described as follows:

- Support for HBM DAQ systems such as QuantumX
- Support for additional devices such as GPS, video, odometers
- Parameterization of all channels and sources
- Offsetting input signals with one another
  - Algebra, logic, …
- Intelligent triggers for recording measurement (start/stop)
  - In the time or frequency range, e.g. sound level
- Visualization of all signals in the following domains:
  - Time (x over t)
  - Channel (x over y), e.g. displacement, angle, rotational speed, velocity
  - Frequency (x over f), e.g. acoustics, vibrations
- Data storage in the desired data format
- Data analysis, modification and storage
  - Export: UFF58, MAT, …
- Report generation (direct printing or via Microsoft Office, e.g. Word or PowerPoint)

The catman®AP software not only offers data acquisition, it also has an integrated math library for online, as well as post-process calculations. The mathematical functions extend from simple algebraic calculations, filters, statistics, classifications such as rainflow or time-at-level, to spectral analyses, to calculation of electrical power and efficiency through simple parameterization.

Practical setup

Our practical setup uses the Microtech Gefell **measuring microphone** M370. In the built-in converter type, there is an electret pressure receiver with a circular characteristic. Constant current from the QuantumX MX410B amplifier feeds the mic and the measured sound pressure is modulated to a voltage signal (IEPE). The measurable frequency range is between 20 and 20,000 Hz (class 1, open air use). The maximum sound pressure level is 130 dB A.

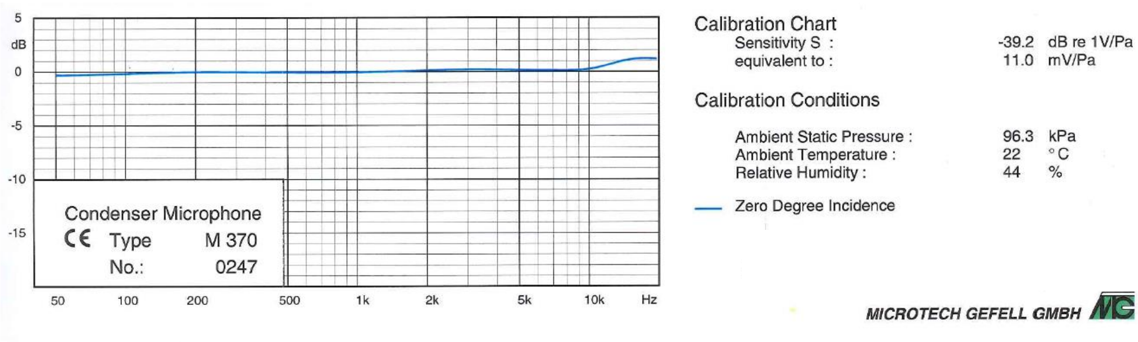


Image caption: MICROTECH GEFELL calibration certificate

The connection to the QuantumX MX410B module uses a BNC to 15-pin Sub HD adapter (HBM order no.: 1-SUBHD15-BNC).

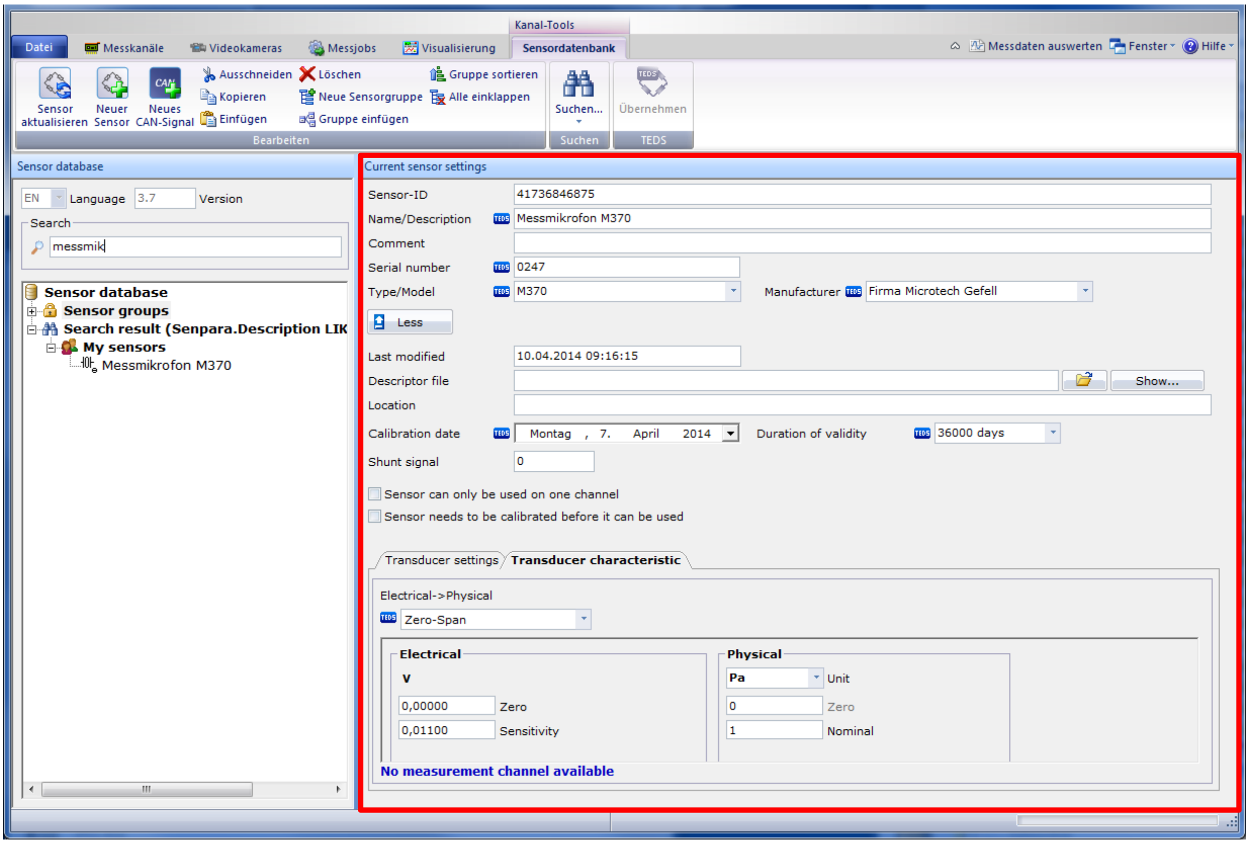
Channel parameterization

In catman®AP, a measurement channel is assigned parameters by the integrated sensor database or directly by the sensor, if this has its own electronic data sheet (TEDS).

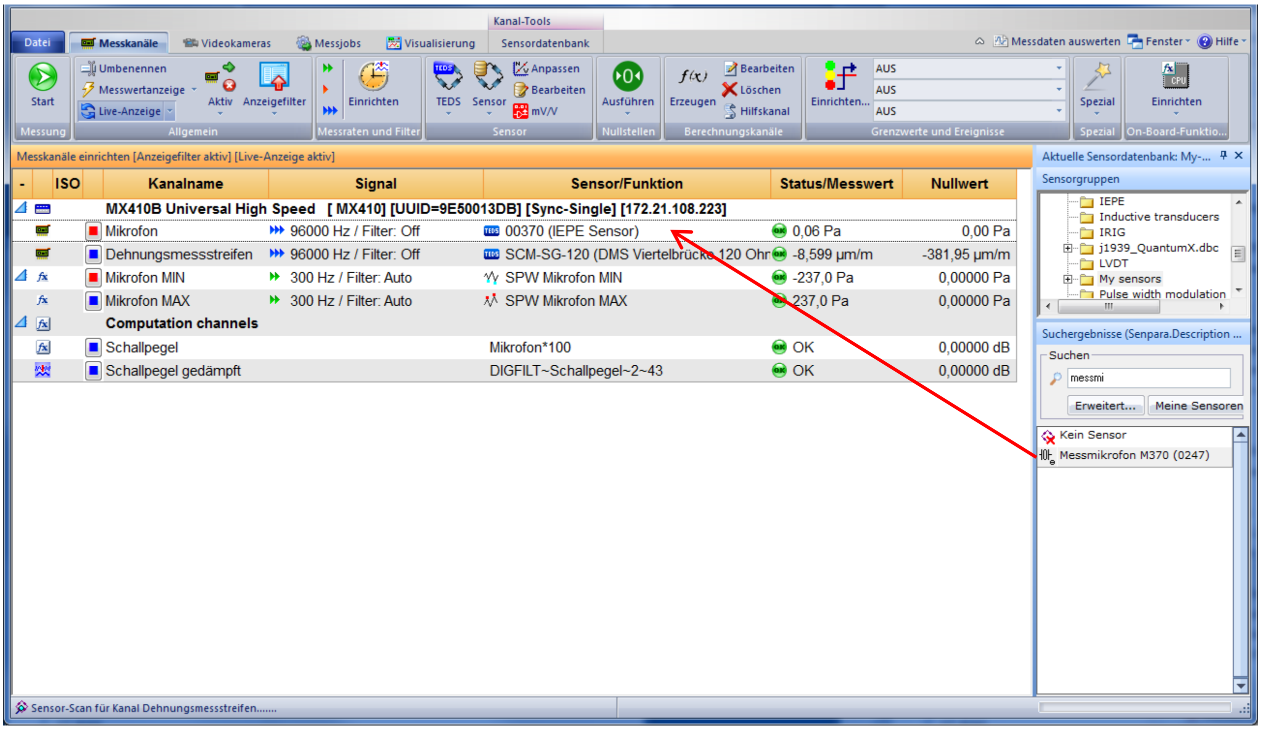
In our example, we are using the sensor database to parameterize the measurement channels. If the correct signal description cannot be found in the sensor database, you can create the relevant data sheet. Using the sensor data sheet makes it easier to set the parameters of each individual channel later and it makes the process reproducible at any time.

The amplitude is the sound pressure expressed in Pascal (Pa). The sensitivity, as taken from the calibration report is 11 mV/Pa.

Digital data sheet of the measuring microphone in the sensor database:



Parameterize the particular channel from the sensor database:



Initial tests with a signal generator:

Image caption: A smartphone as a signal generator

Sound pressure level calculation

Our hearing perceives the sound of varying frequencies as being more or less loud. The sound pressure level or noise level is a psychoacoustic quantity. The signals are filtered for measurement, so that they imitate the properties of human hearing. The weighting curves of these filters are standardized. Weighting curve A, which is also displayed in the unit dB(A) or dBA, is the one mainly used for the analyses.

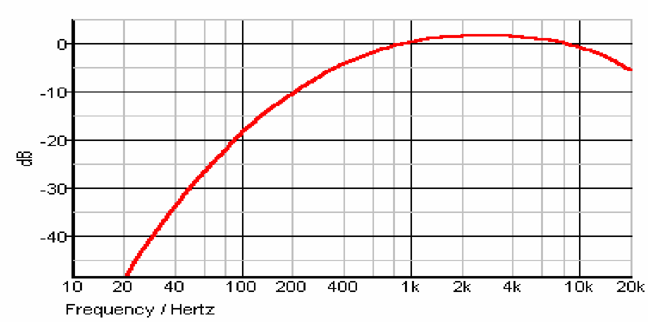
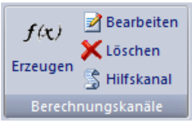


Image caption: A-weighting filter curve

Zero dB(A) corresponds to the threshold of audibility. The threshold of noise pain is just about 130 dB(A). It is very easy to convert sound pressure into the sound pressure level (SPL) by using the "computation channels".

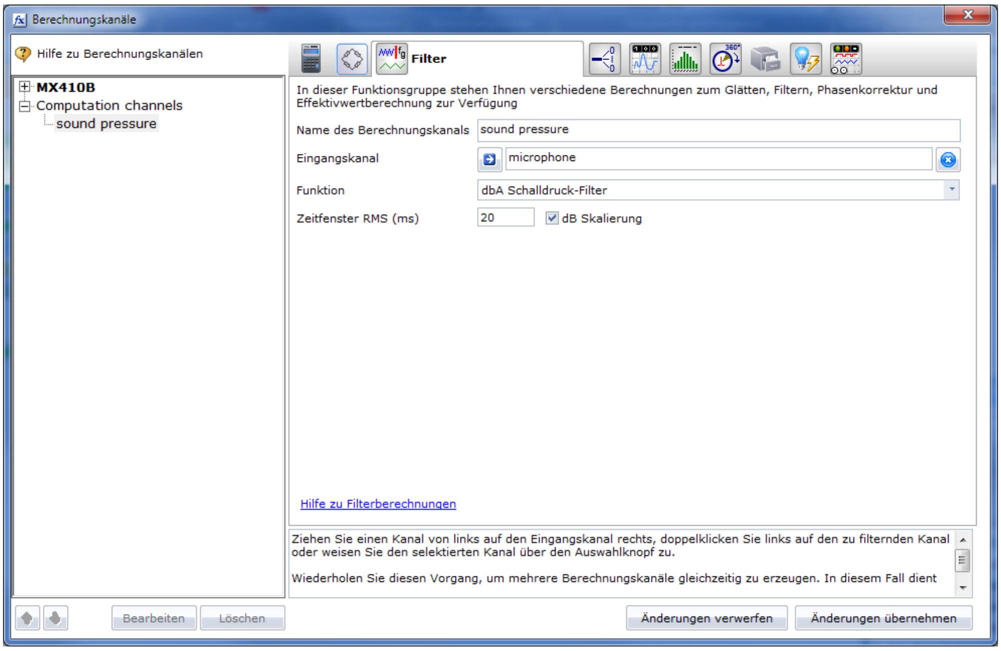
Important: The weighted sound level is neither a physiological nor a physical measurand! The good thing about it is that metrologically, we can also acquire, save and analyze the sound level and the weighted sound pressure level.



Create a new virtual channel using the "**Filter**" dialog and parameterize it:

- New signal name: e.g. sound pressure
- Input channel: e.g. channel 3 MX410B with the signal name microphone
- Filter function: dB(A) sound pressure filter
- Time window for calculating the root mean square value (RMS) in ms: e.g. 20 ms

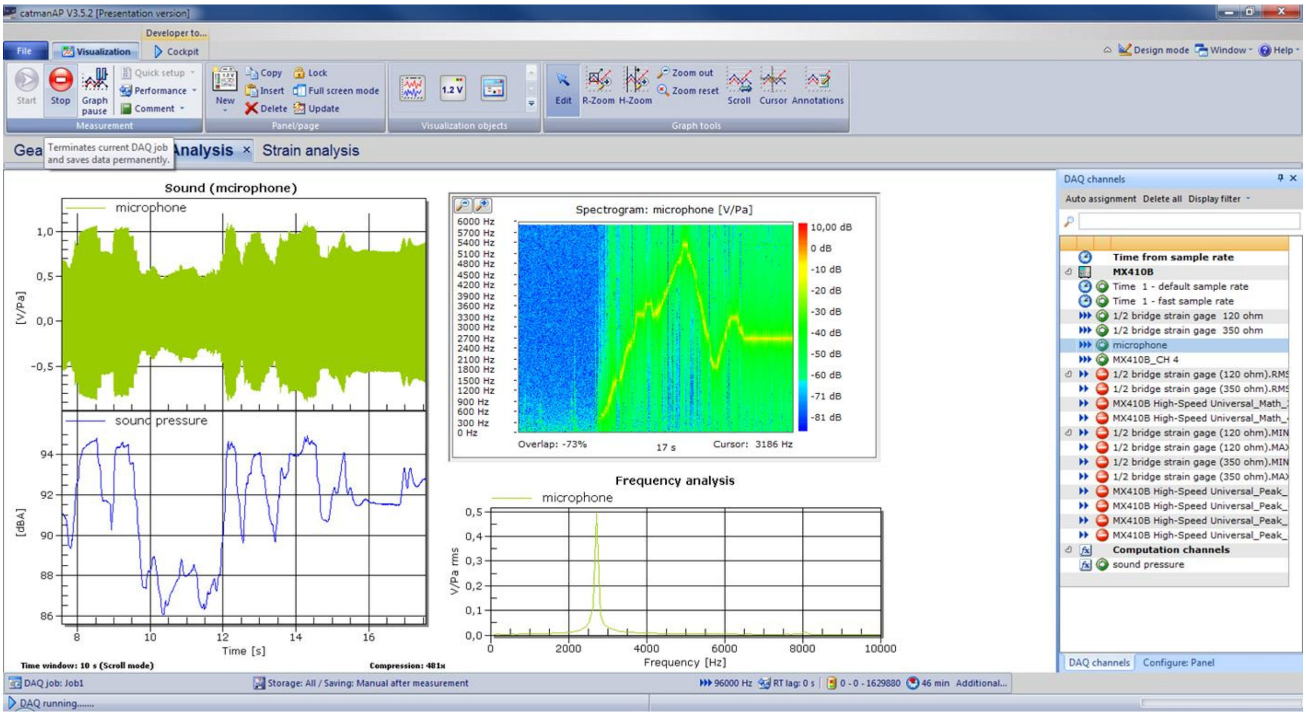
The new computation channel appears in the "Computation channels" list.



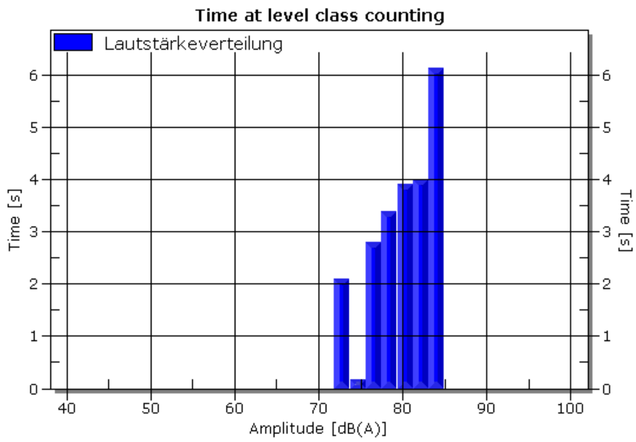
To use the dBA filter catman AP or catman Easy + EasyMath module is necessary.

Signal analysis in the time domain and frequency range

Instrument the sound pressure and level in diagrams over **time** (y-t) or over a second **measurand** (x-y) such as displacement or the angle of rotation or in the **frequency range** (y-f).



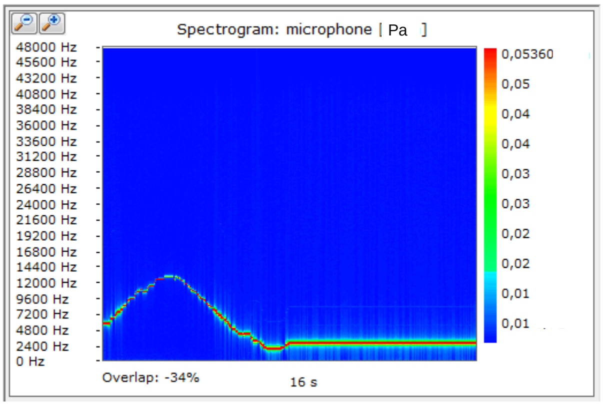
Detail – Classifying the sound pressure level over the measurement period



Detail – 2D frequency analysis

The signal analysis in the frequency range by means of a Fast Fourier Transform (**FFT**) needs a few parameters, such as the number of measured values, which should be used to calculate the amplitude spectrum. The basic rule of thumb is that the more measured values you include in the FFT, the more accurate the resolution in the frequency range. The window function is another parameter. It determines the weighting to be applied for sampling values derived from sampling a signal within a segment (window) when they are used in the calculation. If multiple channels are assigned to the graph, the spectra of the channels can also be displayed as the vector sum.

Detail - Frequency analysis in the 3D spectrogram



Detail – Frequency analysis in a 3D waterfall diagram
In dynamic operation, it makes particular sense to display the time spectral characteristic. The so-called waterfall diagram can be used for this, as well as the spectrogram. Amplitude spectra are staggered and simultaneously displayed in 3D. The view can be freely rotated.

Analyzing recorded measurement data

Switch to data analysis mode (post-process). Frequency analysis in the post-process mode uses the FFT to calculate a spectrum (an amplitude, phase or power spectrum). The calculation may be performed multiple times over a part of the measurands in some circumstances depending on the frequency resolution. The advantage of this method is that the available measurands can be analyzed best if there is not a 2n number of measurands present. For frequency resolution either select Number of points from FFT and enter the number of values (points) under FFT or define the frequency resolution you want.

If you specify a frequency resolution, depending on the number of available measurands and the data rate you are using, either all measurands will be used for a calculation or several spectra may be calculated, each over part of the measurands. In this case the mean value will then be formed from all calculated spectra unless you activate the Joint Time Frequency Spectrum option.

You can activate Generate Frequency Data Set to have the frequency channel available for export as well. The channel is not needed for the display in an overview graphic.

Video analysis

QuantumX has universal inputs, so that a wide range of physical quantities such as voltage and current, torque, rotational speed, temperature, acceleration, vibration, noise or the signals of digital communication buses can be acquired electrically at the same time. The catman®AP software can also call on up to 4 video sources for analysis.
In the example below, the mic is measuring the sound and the strain gage is measuring the impulse of a hammer impact

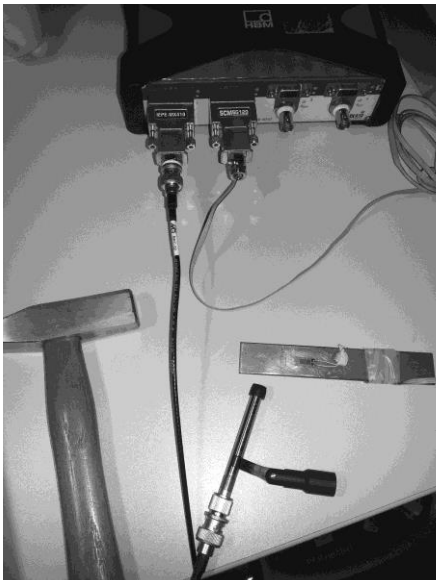
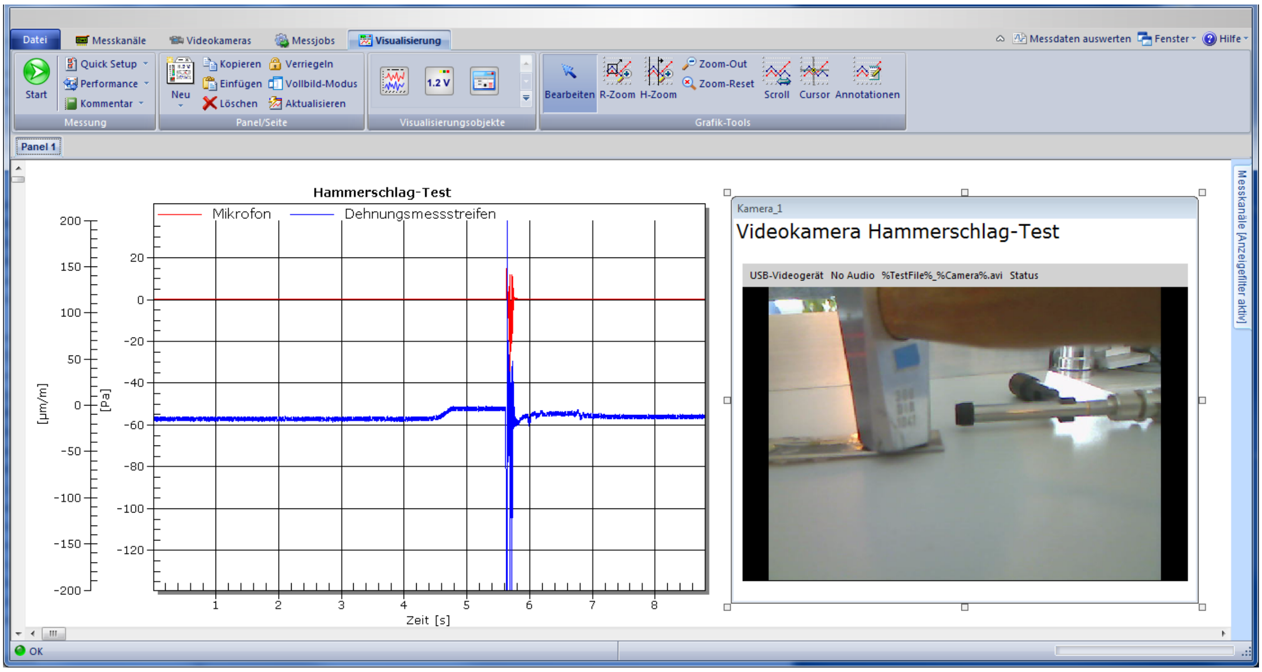


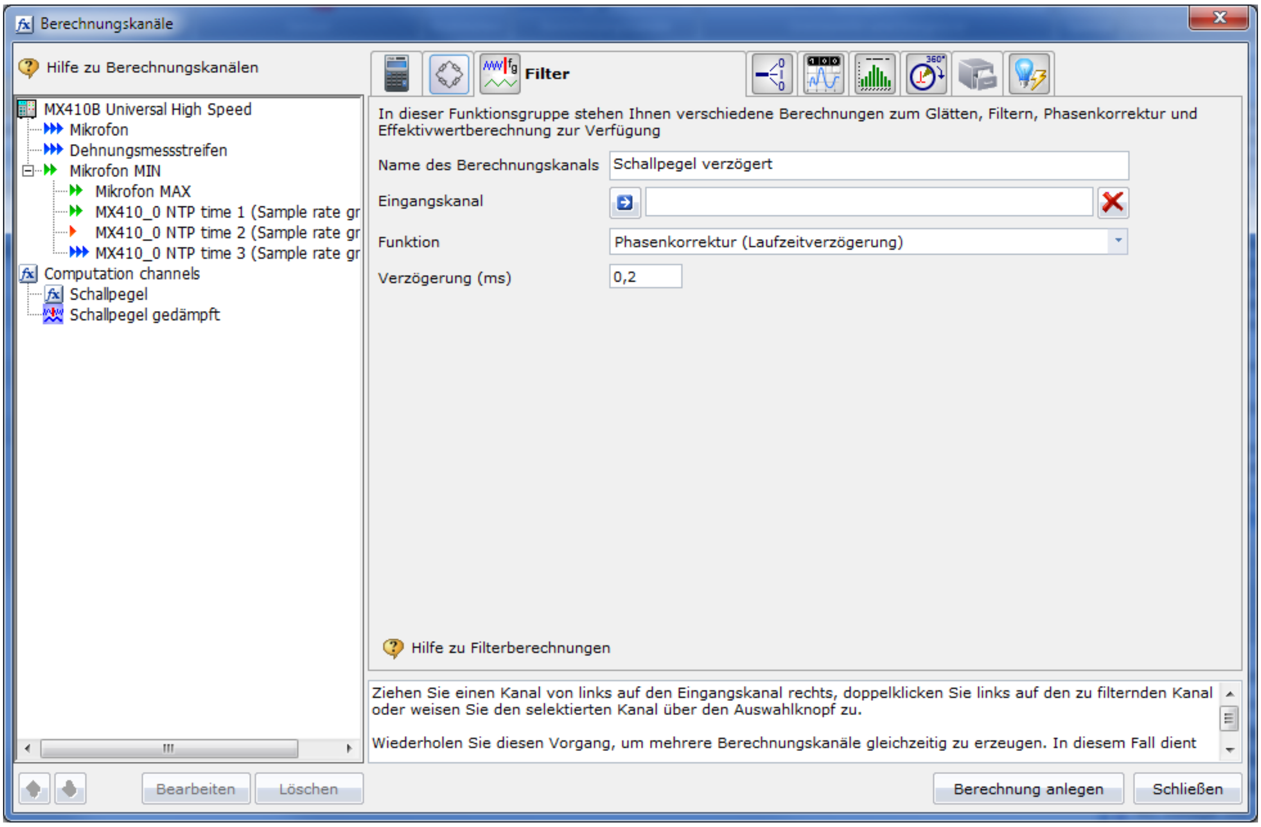
Image caption: Metal plate with SG, mic and hammer

For a synchronized investigation of the measured quantities, sound pressure and SGs, the sample rates and filters of the channels should be identical. A video image provides additional information about the physical process.

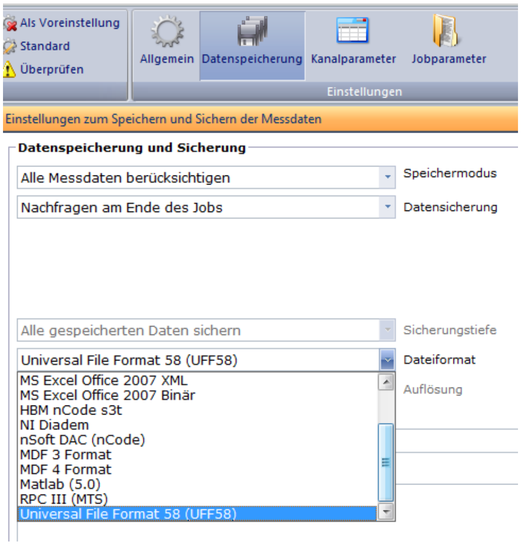


Is there a phase delay between the signals?

Has skew been identified between the mechanical and acoustic signals and can this be corrected. Dialog: Computation channels/filters/phase correction



Exporting data to other formats



- UFF58 – Universal File Format 58, is widespread in dynamic structural analysis
- MAT – MATLAB
- MDF 3 or 4 – ASAM standards

Test report

There is much freedom of expression for report generation in Microsoft Word or PPT. The graphic displays of a measurement or analysis project in catman®AP can automatically be copied to a test report in Word format at a pre-defined bookmark (e.g. tt1 in the Office tab). Right-click on a display and follow the "Export/Print" dialog.
Example: Hammer impact

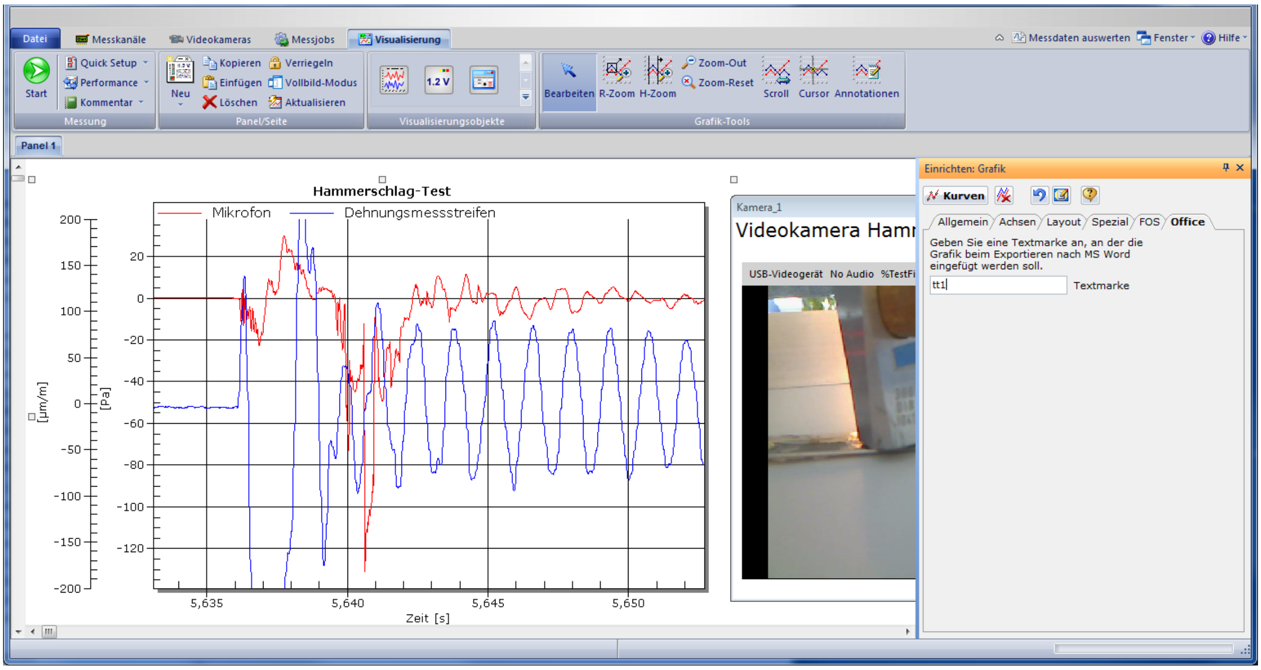
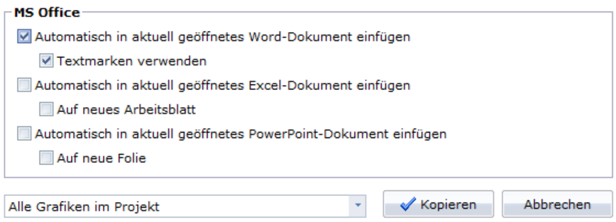


Image caption: Bookmark definition



Transfer display object from catman to Word:

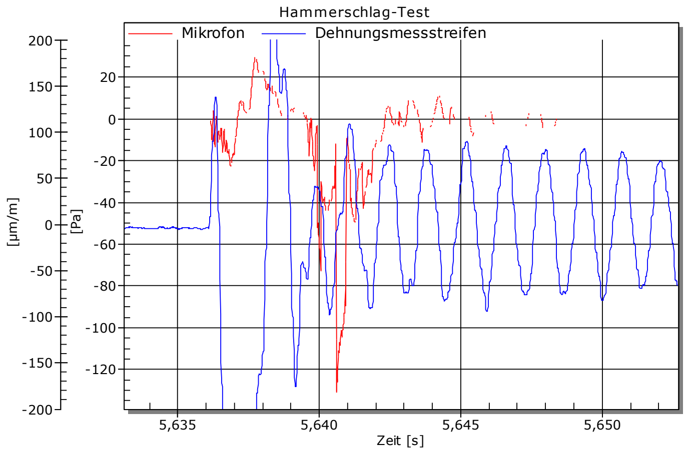


Image caption: Display object automatically copied to Word

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